ModelID, an Interactive Program for Identification of MPC Relevant State Space Models

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Introduction

- Model Predictive Control is one of the most successful advanced control technologies
- The time consuming part of industrial MPC commissioning is generation of data and identification of models
- Successful implementation of MPC requires a good model for the prediction

This paper describes a practical work flow during identification of linear time invariant state space models for MPC controllers, using the new $ModelID$ system identification program.
The paper show how to estimate time delays, and demonstrates the use of instrumental variable methods on processes, which cannot be adequately described using ARX models

ModelID

- *ModelID* is designed for process engineering practitioners, who want to develop models without having a detailed knowledge of system identification theory or computer programming.
- The identification cycle is supported by many graphical outputs, providing valuable information about the process and the evaluated model.
- *ModelID* is developed for the windows platform, using the C#/.NET based library *MPCMath*.

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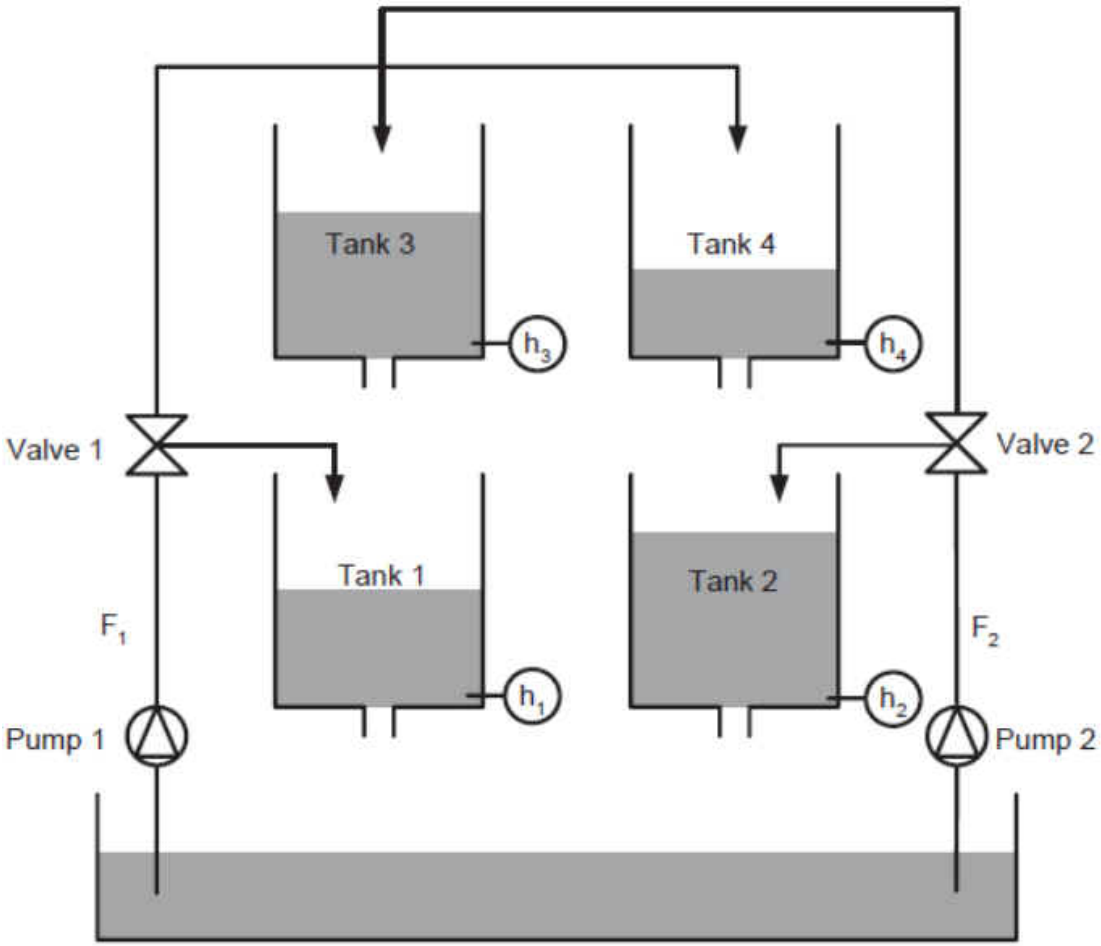
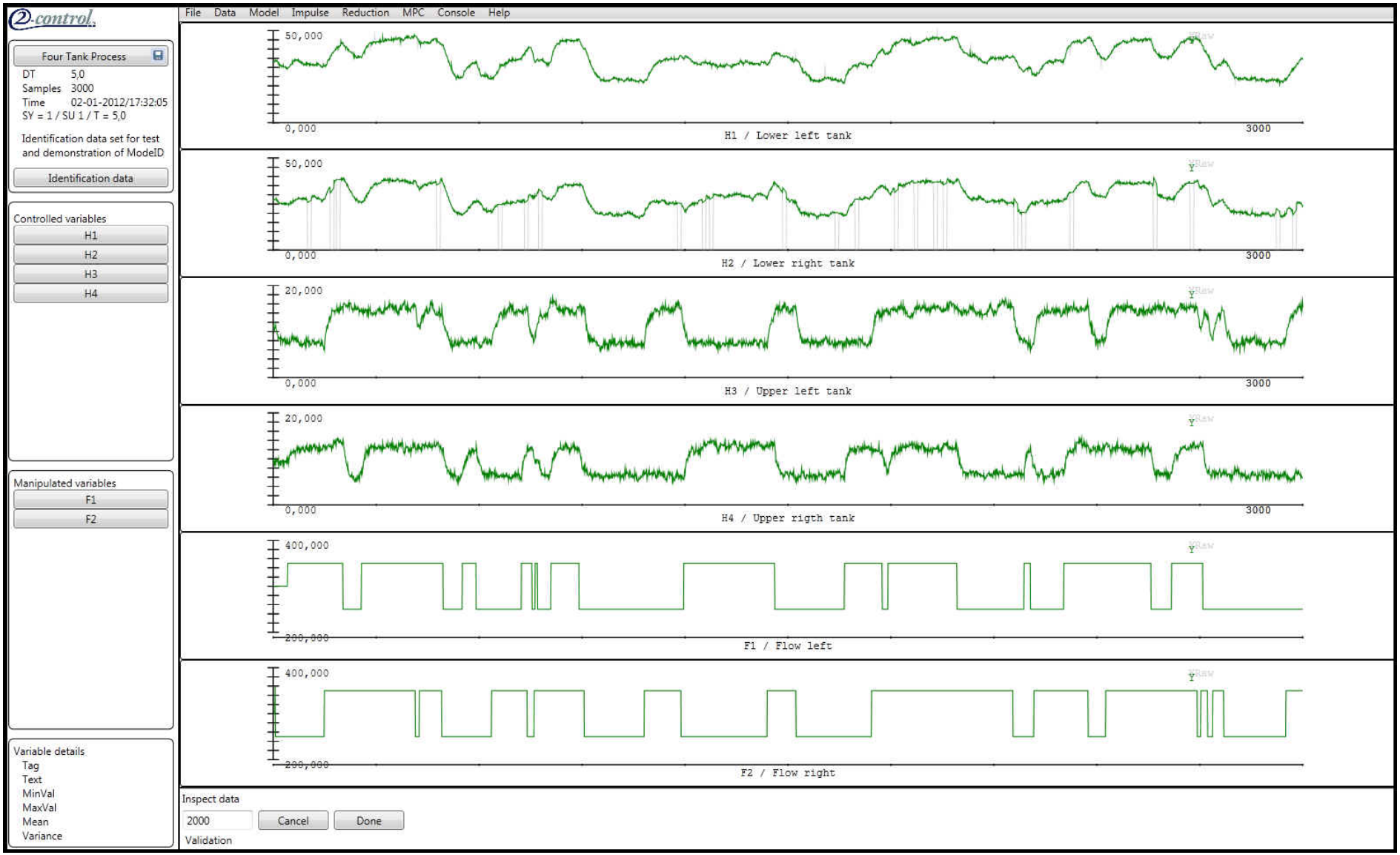
- MPC tool.
  - Initial tuning and test of MPC controller.

Four Tank Process



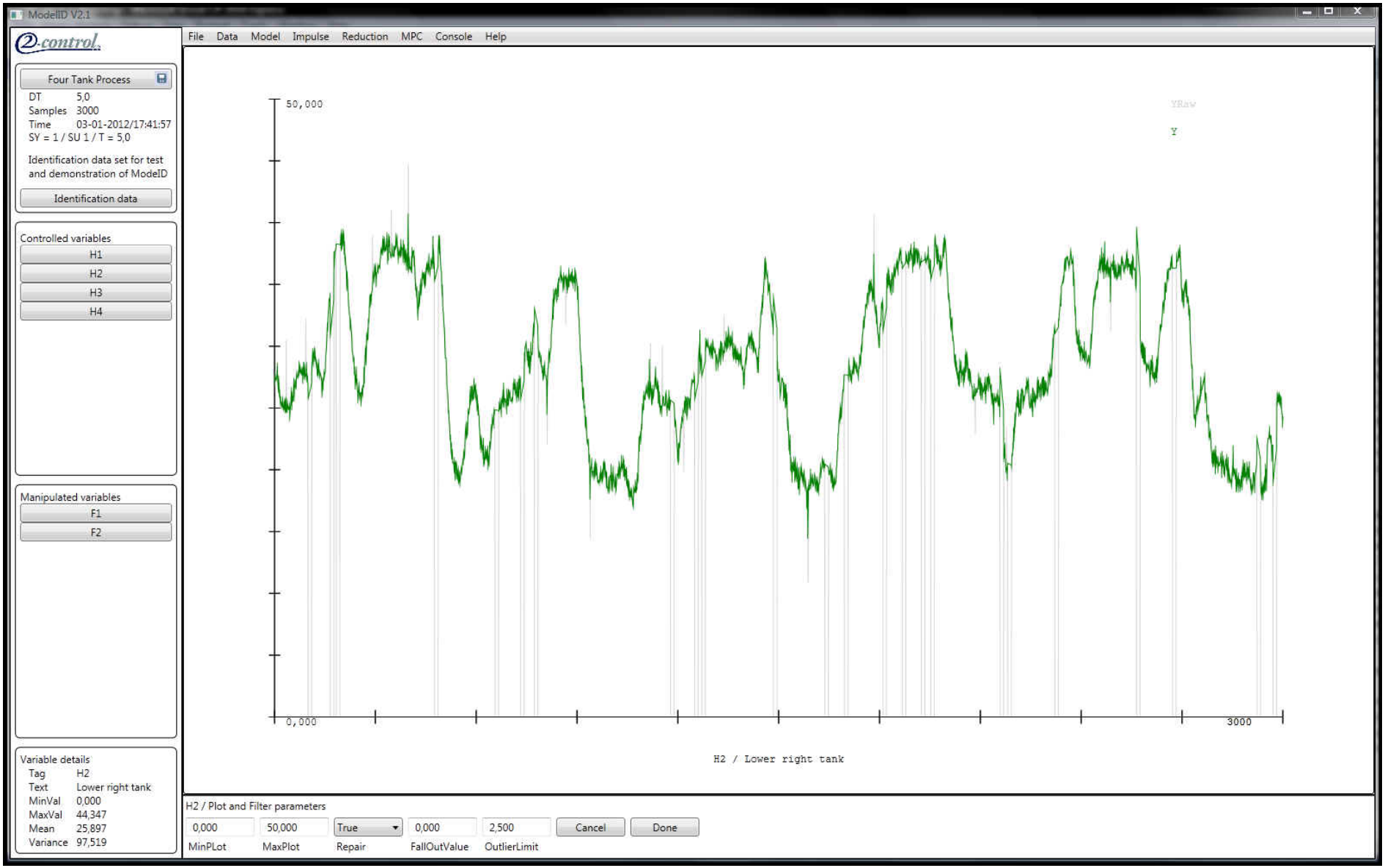
Four tank process used to illustrate process identification work flow

Four Tank Process, Data



Simulated data for for four tank process

Data tool



Data tool: Removal of Spikes and fall outs.

Model tool, The identifications procedure I

$$Y(t) = G(q)U(t) + H(q)E(t)$$

$$G(q) = \frac{B(q)}{A(q)} \qquad H(q) = \frac{\Lambda}{D(q)}$$

where the polynomials are

$$A(q) = I - \sum_{j=1}^{sy} A_j q^{-j} \qquad B(q) = \sum_{j=1}^{su} B_j q^{-j}$$

$$\Lambda = \begin{pmatrix} \lambda_1 & 0 & \dots & 0 \\ 0 & \lambda_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \lambda_{n_y} \end{pmatrix}$$

$$D(q) = I - \sum_{j=1}^{sd} D_j q^{-j}$$

Model tool, The identifications procedure II

The deterministic one step predictor

$$\hat{Y}(t|t-1) = \sum_{j=1}^{sy} A_j Y(t-j) + \sum_{j=1}^{su} B_j U(t-j)$$

Predictor for the individual controlled variable

$$\hat{y}_i(t|t-1) = \sum_{j=1}^{sy} a_{i,j} Y(t-j) + \sum_{j=1}^{su} b_{i,j} U(t-j)$$

where $a_{i,j}$ and $b_{i,j}$ are the i rows of A_j and B_j , $1 \leq i < n_y$.
The prediction errors for y_i

$$\epsilon_i(t) = y_i(t) - \hat{y}_i(t)$$

Model tool, The identifications procedure II

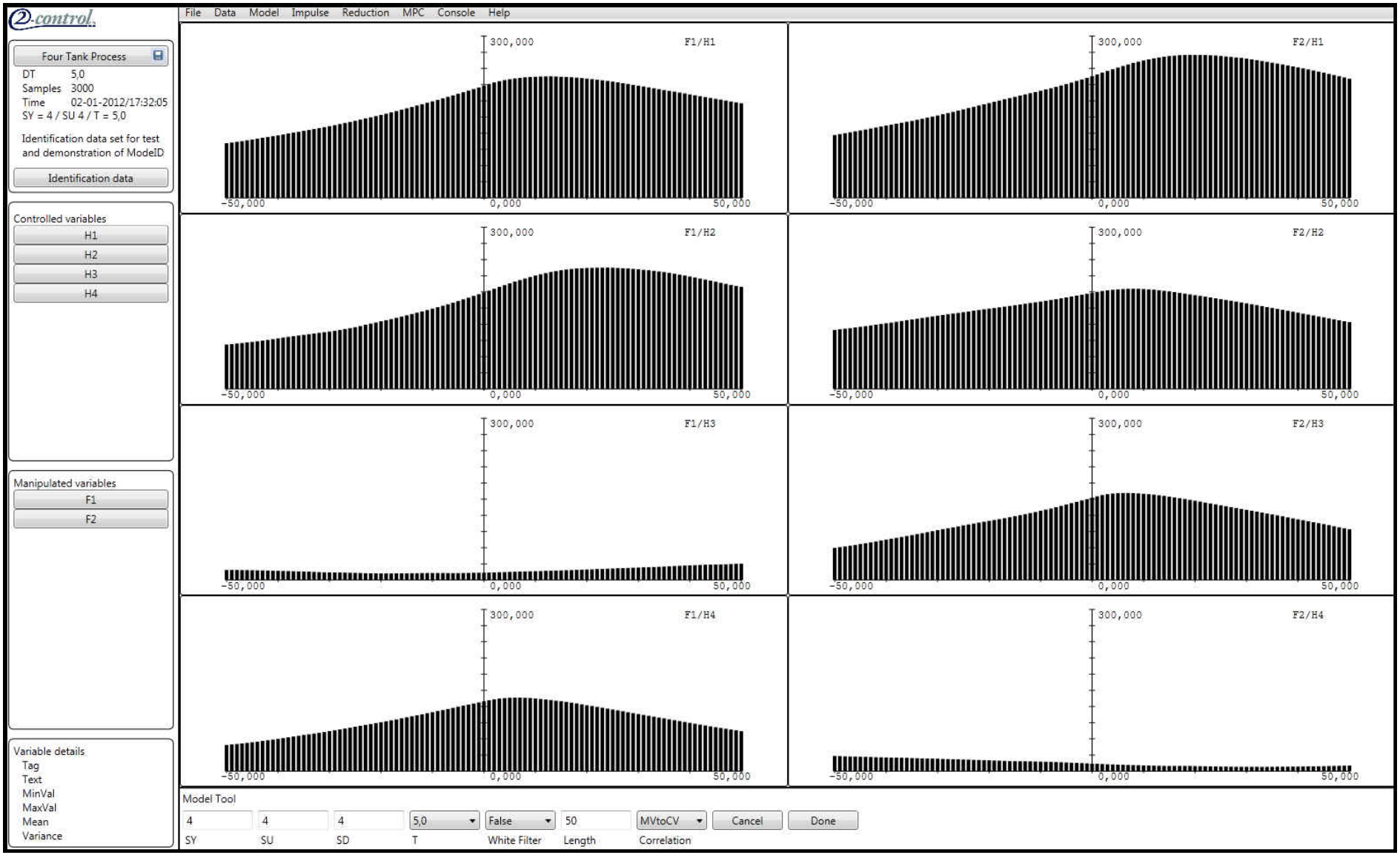
Having n samples of $Y(t)$ and $U(t)$, $0 \leq t < n$, estimated $\hat{A}(q)$ and $\hat{B}(q)$ can be determined minimizing n_y MISO problems

$$V_i = \sum_{t=1}^{n} \ell_i(F_i(q)\epsilon_i(t))$$

where ℓ_i are suitable norm functions.
Linear low pass filter reducing the effect of high frequency noise signals

$$F(q) = \frac{1-f}{1-fq^{-1}} \qquad 0 \leq f < 1$$

Model tool, Correlations



Model Tool: Four tank process correlations.

Model tool, Whitening filter

Try to make the manipulated variable $u(t)$ as white as possible with a whitening filter
The whitening filter $F_{wh}(q)$ is determined by modelling the manipulated variable as an AR-process with dimension 10.

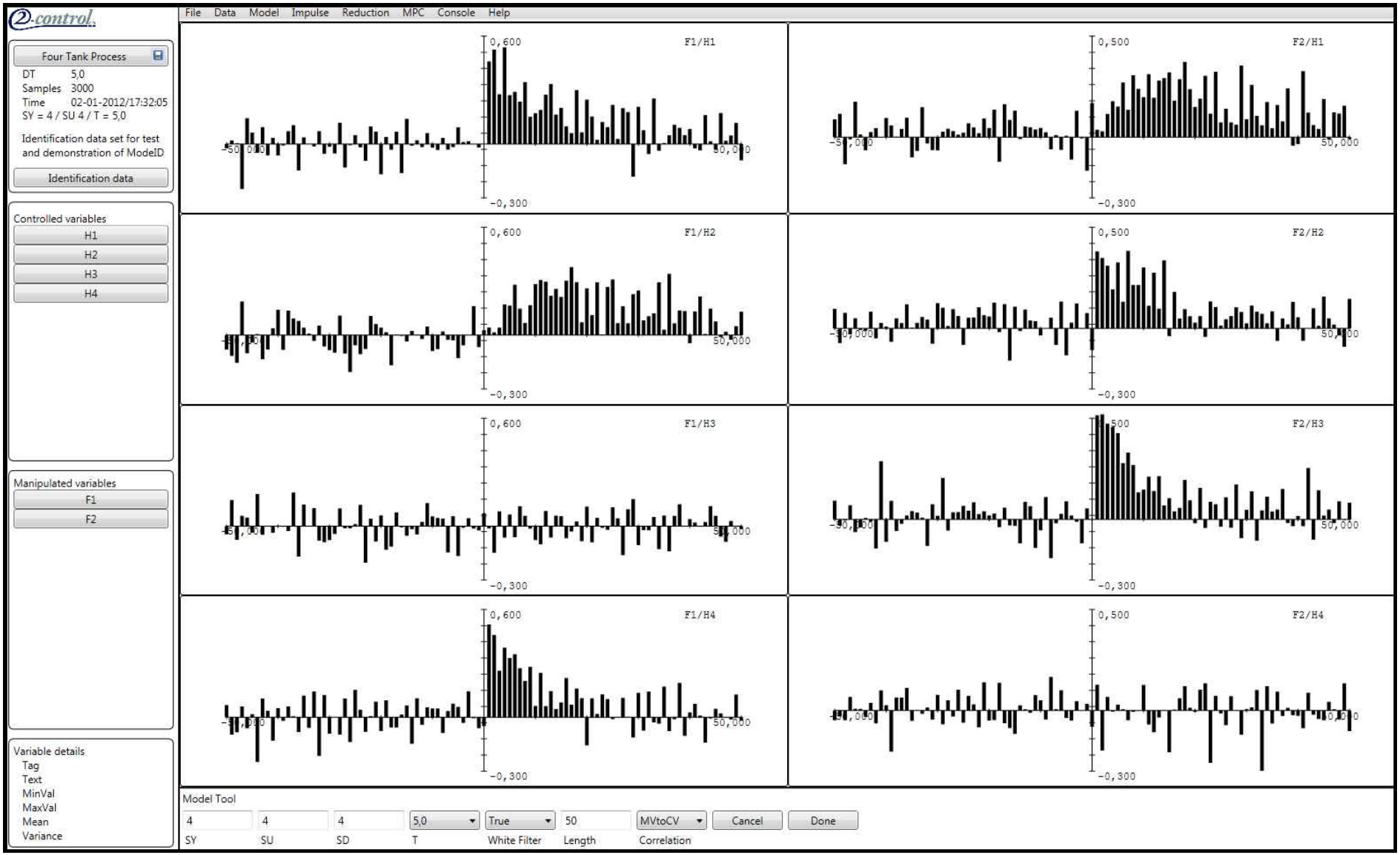
$$F_{wh}(q)u(t) = e(t)$$

Filtered values

$$u_F(t) = F_{wh}(q)u(t)$$

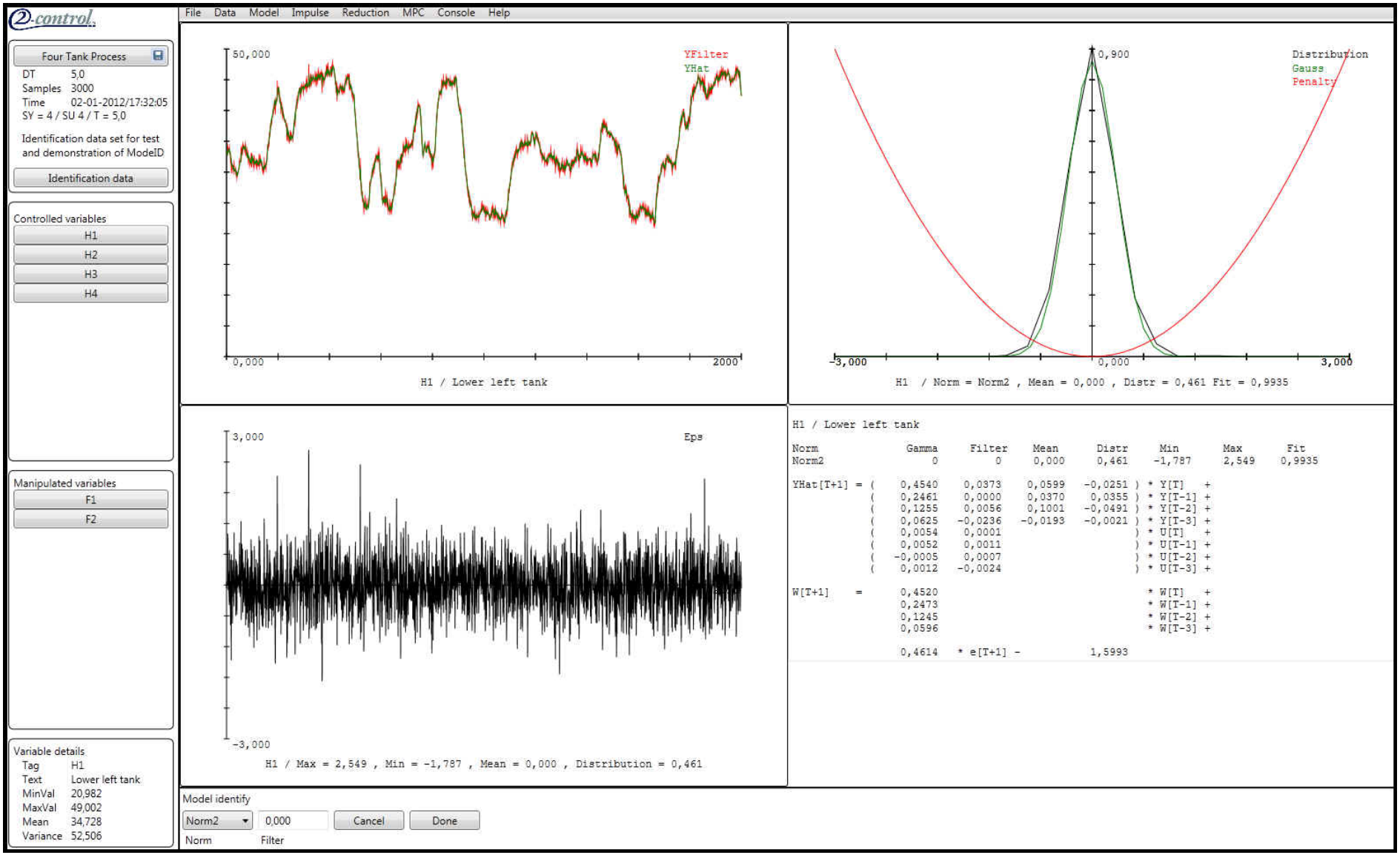
$$y_F(t) = F_{wh}(q)y(t)$$

Model tool, Correlations with whitening filter



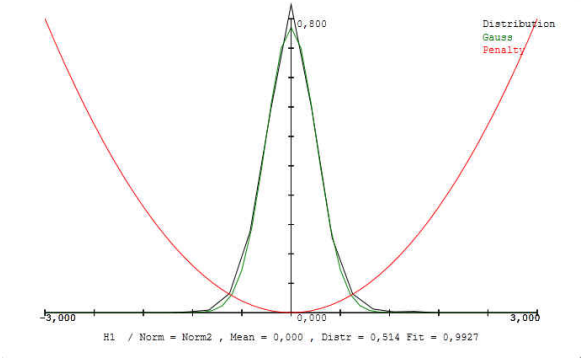
Model tool: Correlations with white filter option.

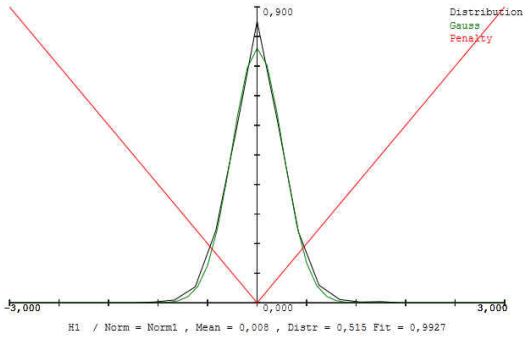
Model tool, MISO identification

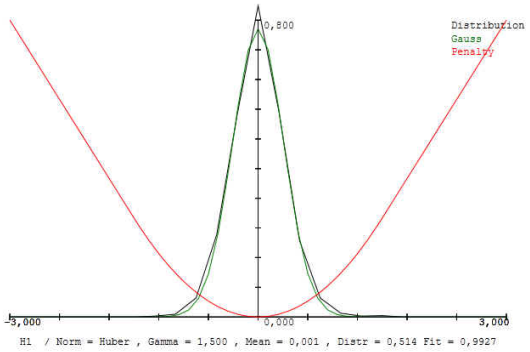


Model Tool: MISO identification

Model tool, Norms







ℓ_2

- \+ Standard norm
- \+ QR or Cholesky factorization algorithms
- \- Sensitivity to outliers

ℓ_1

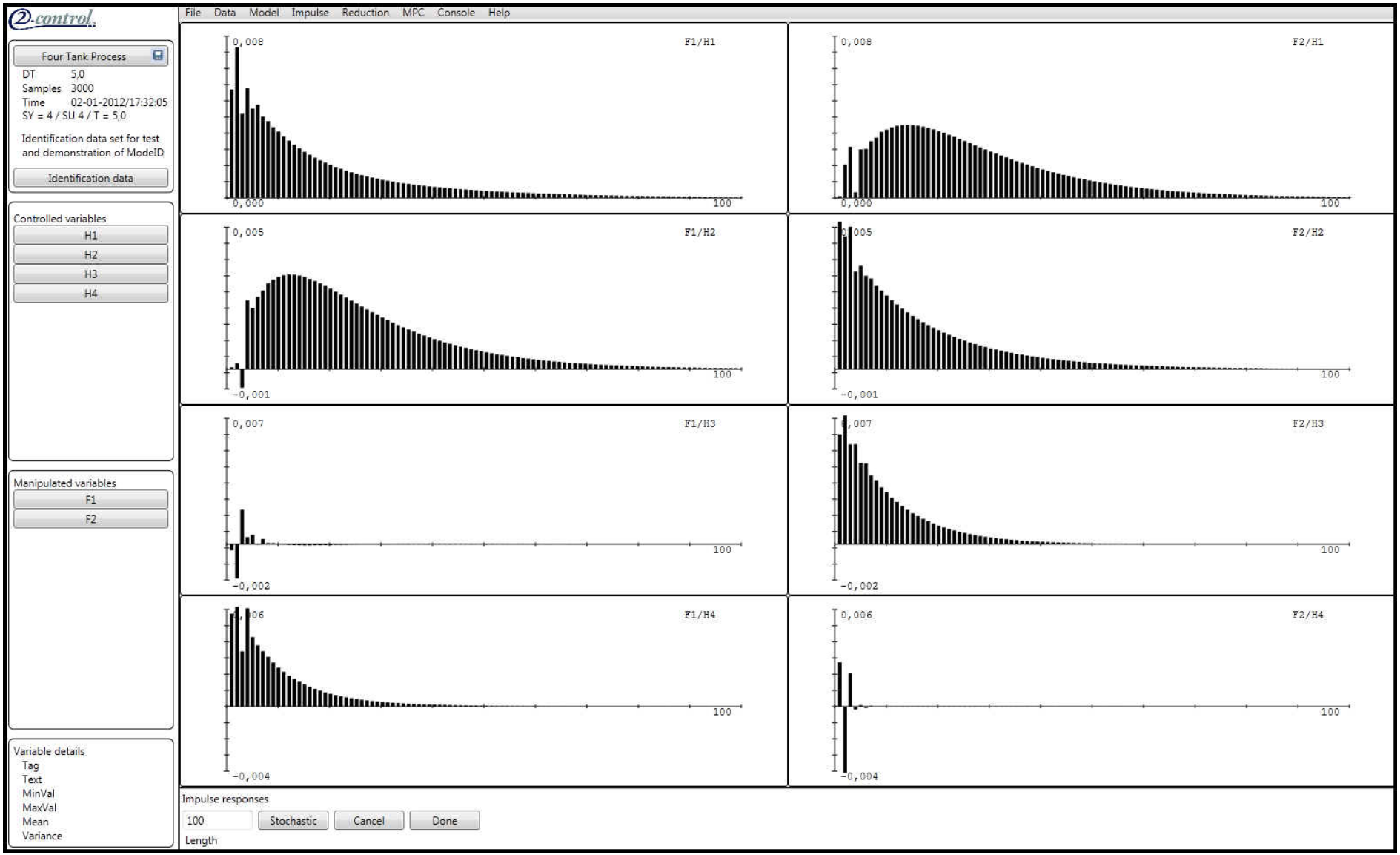
- \+ Robust identification
- \+ Linear Programming
- \- cpu load acceptable

ℓ_{Huber}

- \+ Compromize between ℓ_2 and ℓ_1
- \+ Quadratic Programming
- \- cpu load acceptable

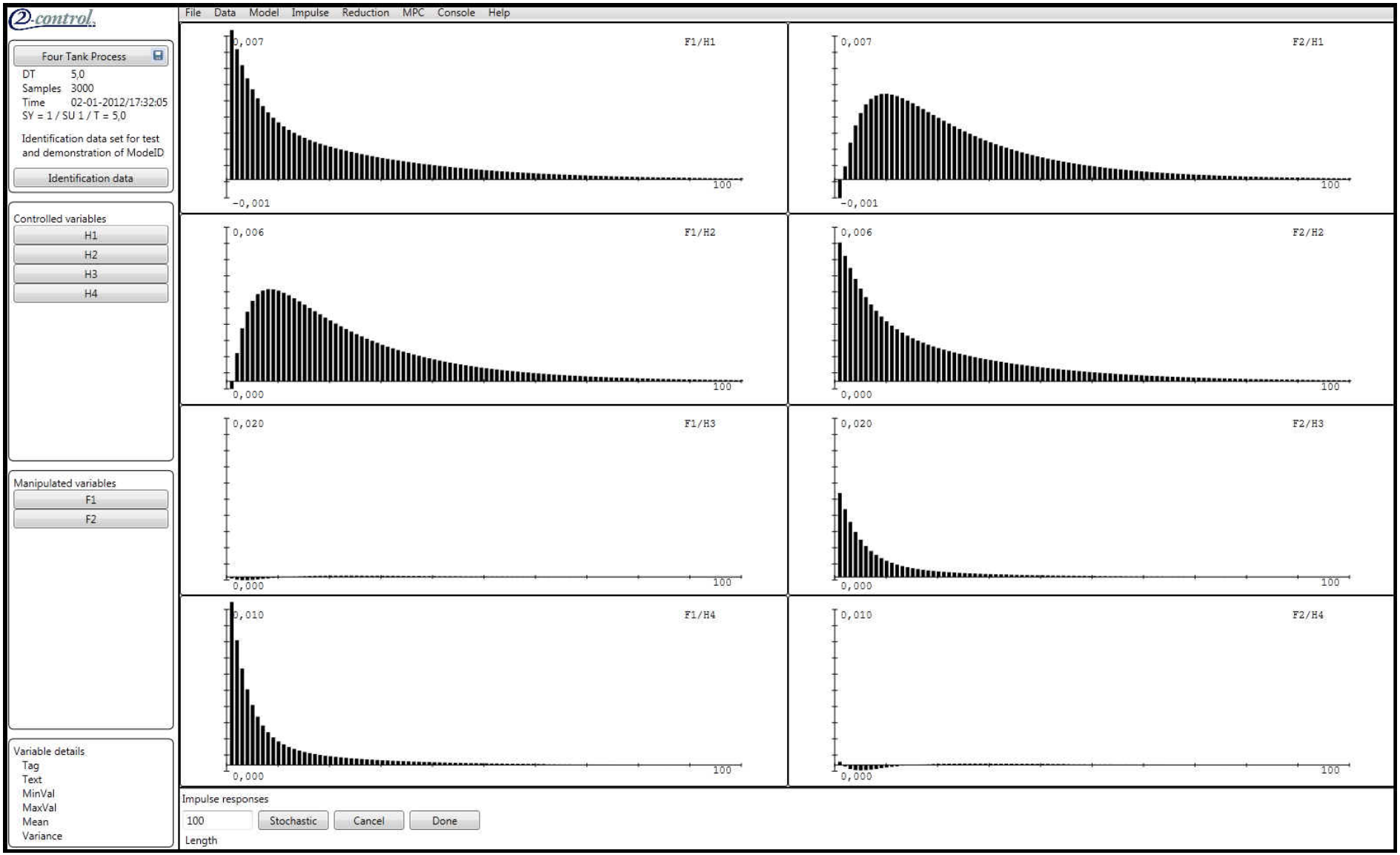
$$\ell_{Huber}(\epsilon_i) = \begin{cases} \epsilon_i^2 & |\epsilon_i| \leq \gamma \\ \gamma|\epsilon_i| - \gamma^2 & |\epsilon_i| > \gamma \end{cases}$$

Impulse tool. SY, SU and SD = 4



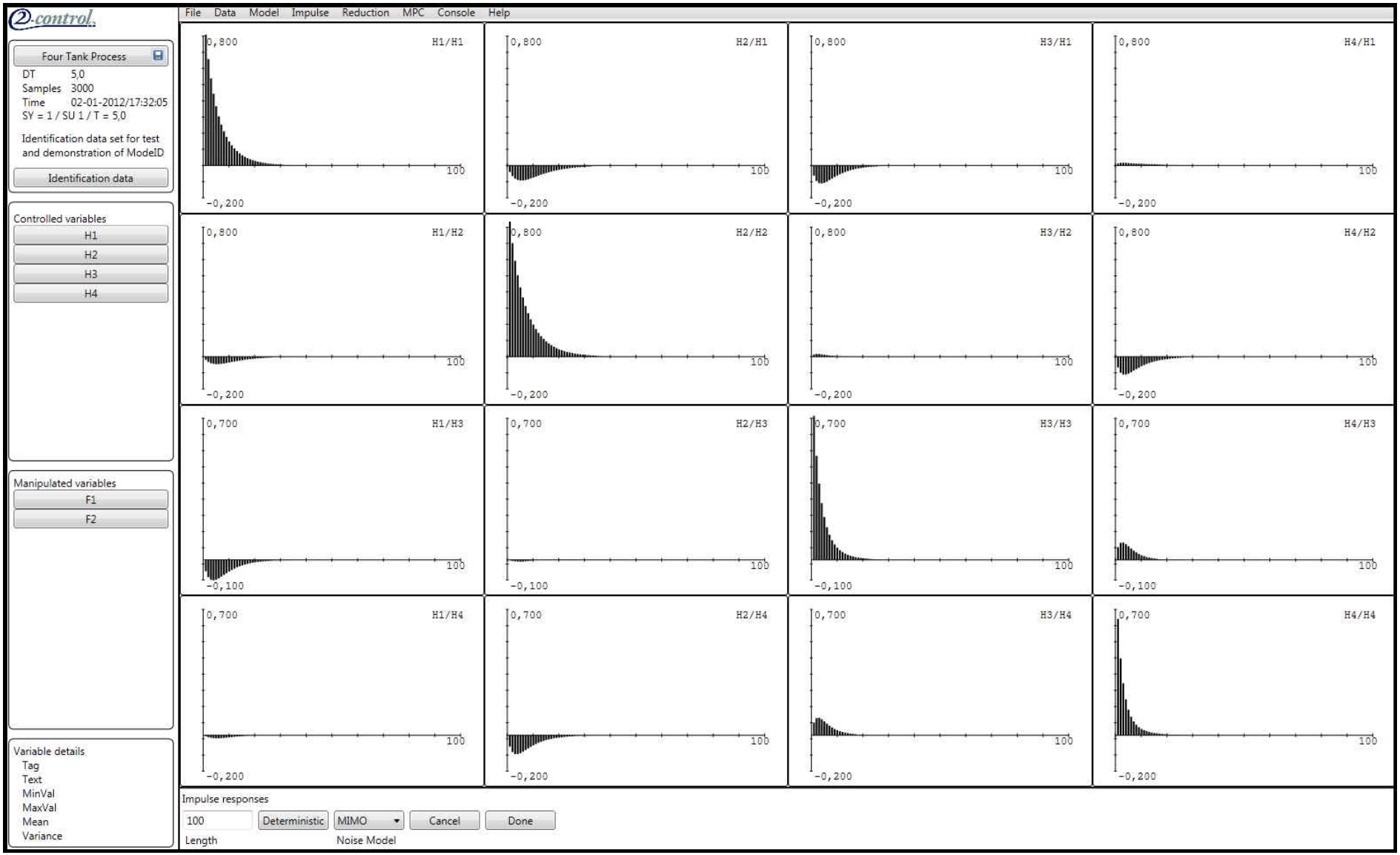
Oscillating impulse responses with too high system dimensions

Impulse tool. SY, SU and SD = 1



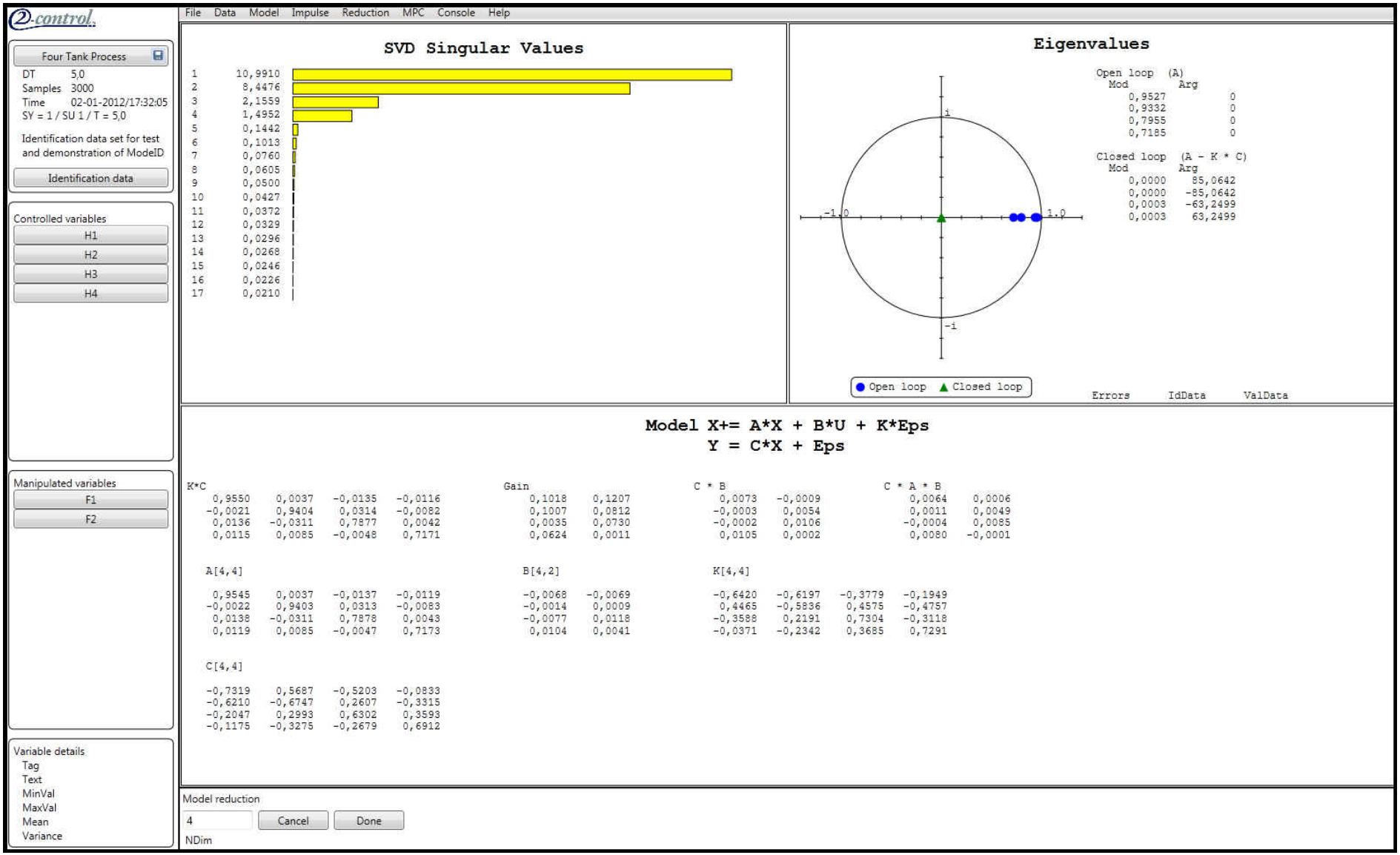
Oscillating impulse responses correct system dimensions

Impulse tool. SY, SU and SD = 1



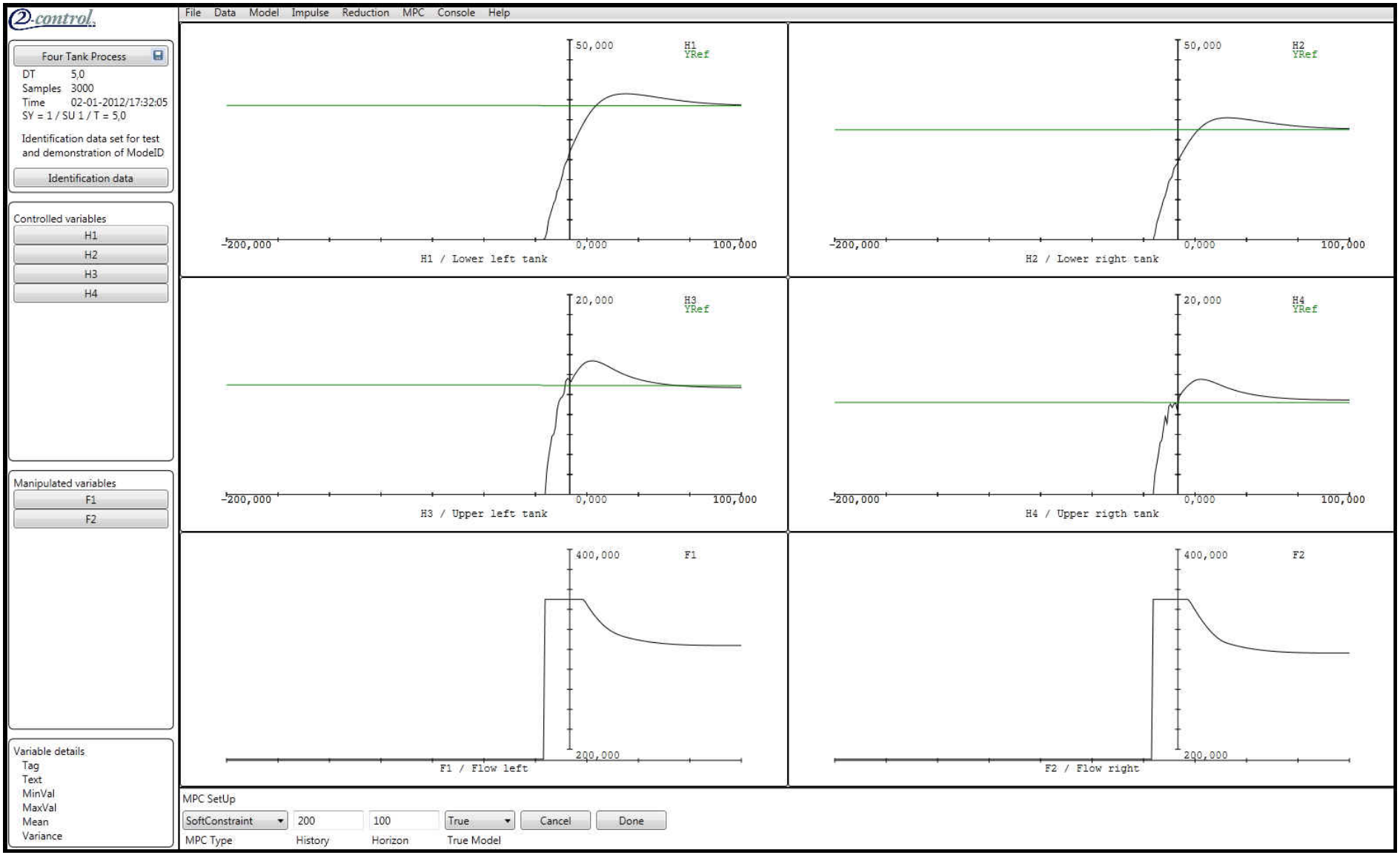
The impulse responses for the MIMO stochastic model.

Reduction tool and State Space model



The reduction tool creates state space models in innovation form.

MPC tool



MPC tool: Controlling the four tank process

Estimating Time delays

- Proper estimation of time delays is important in order to minimize the dimension of the identified state space model.

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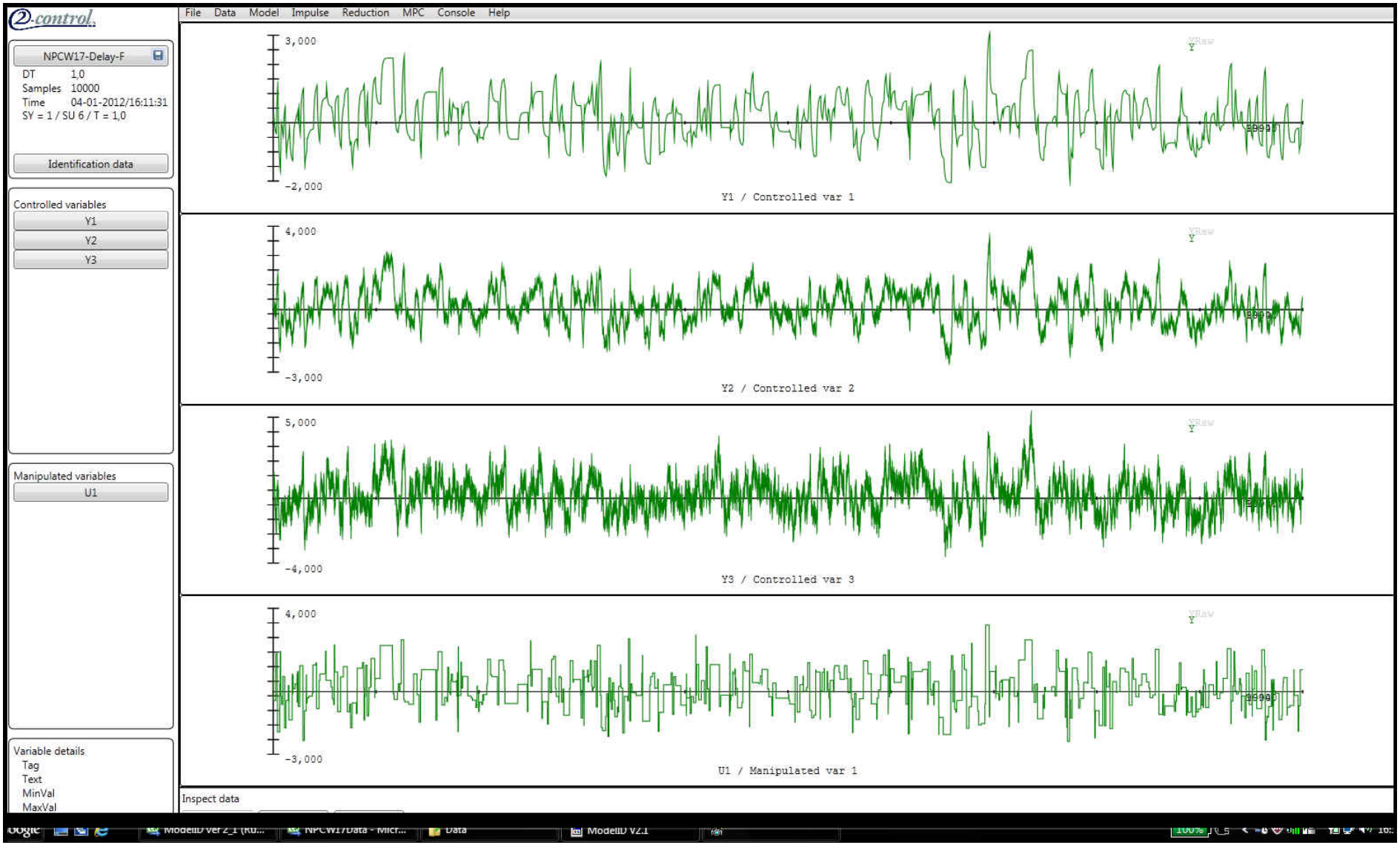
- Data from first order and second order processes with pure time delays will be used to illustrate the problem.
- The first order system, with a delay of 5 second and a time constant on 10 seconds, is given by

$$y(t) = 0.9048y(t-1) + 0.0952u(t-6) + \sigma * e(t)$$

- The second order ARX system, with with a time delay of 5 second, a time constant of 10.0 second and damping of 0.5, is given by

$$\begin{aligned} y(t) = 1.8953y(t-1) - 0.9048y(t-2) \\ + 0.0047u(t-6) + 0.0047u(t-7) + \sigma e(t) \end{aligned}$$

First order ARX, $\sigma^2 = (0.0, 0.01, 0.1)$



First order ARX processes signal with increasing noise levels.

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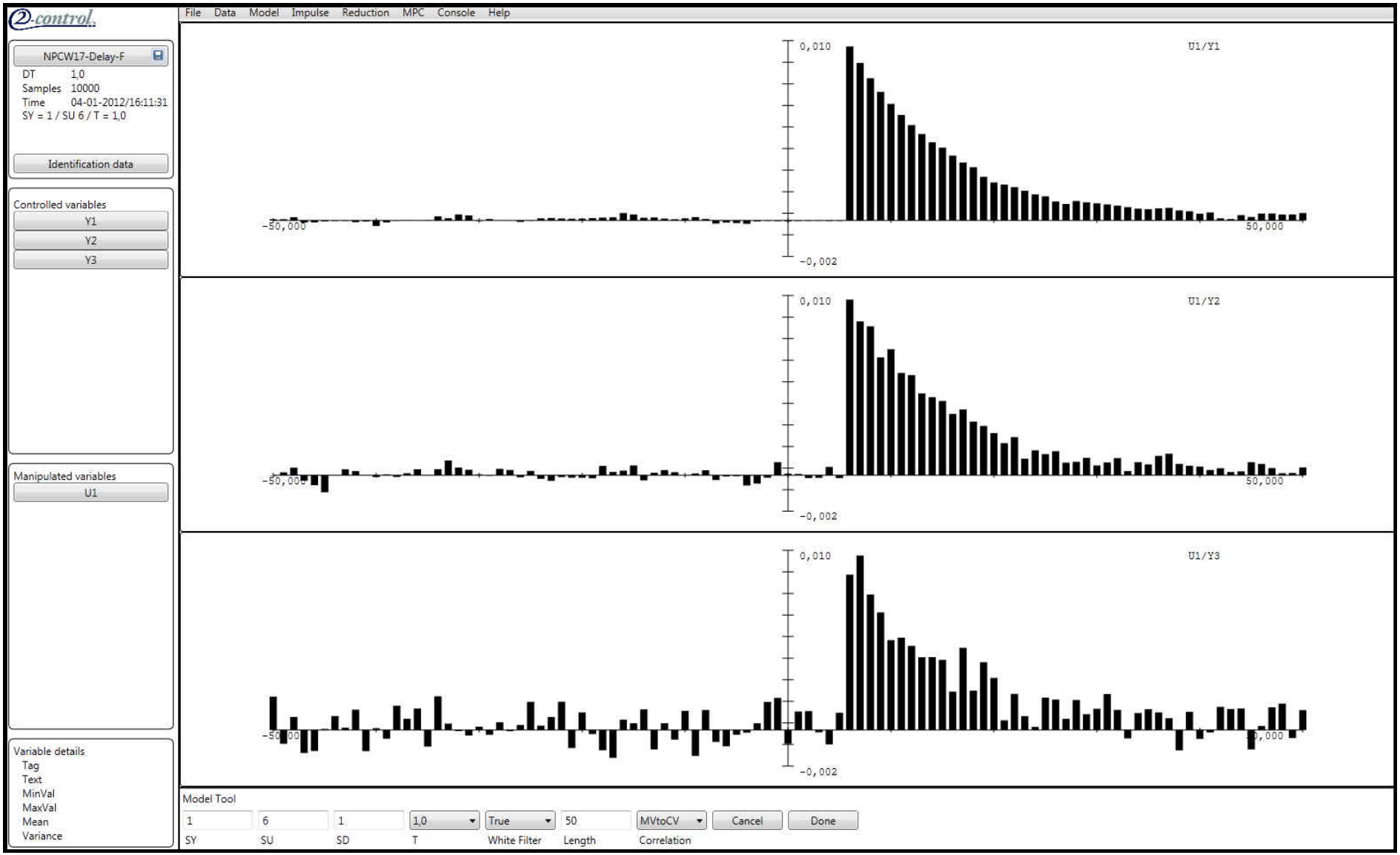

First order ARX processes cross correlations.

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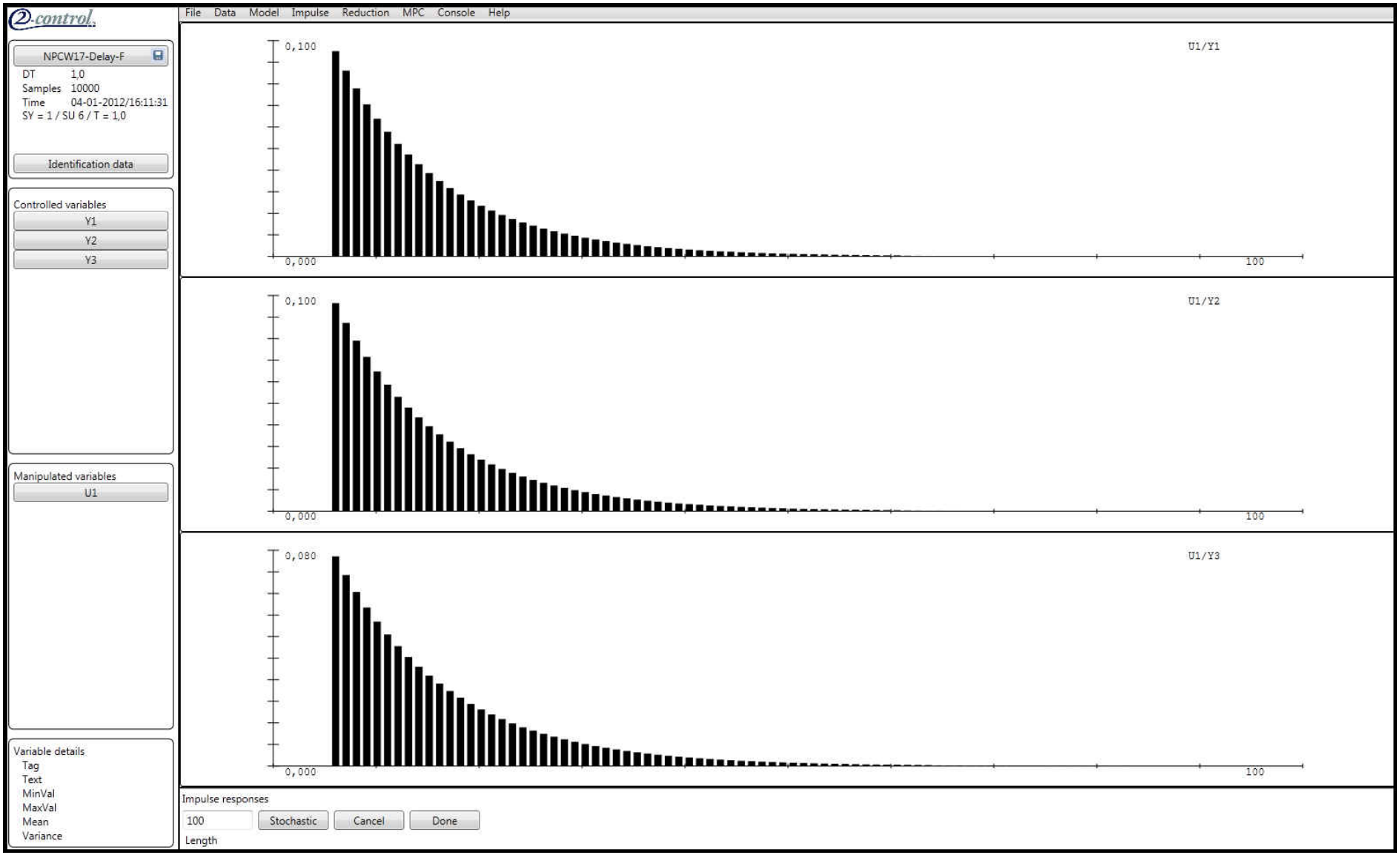
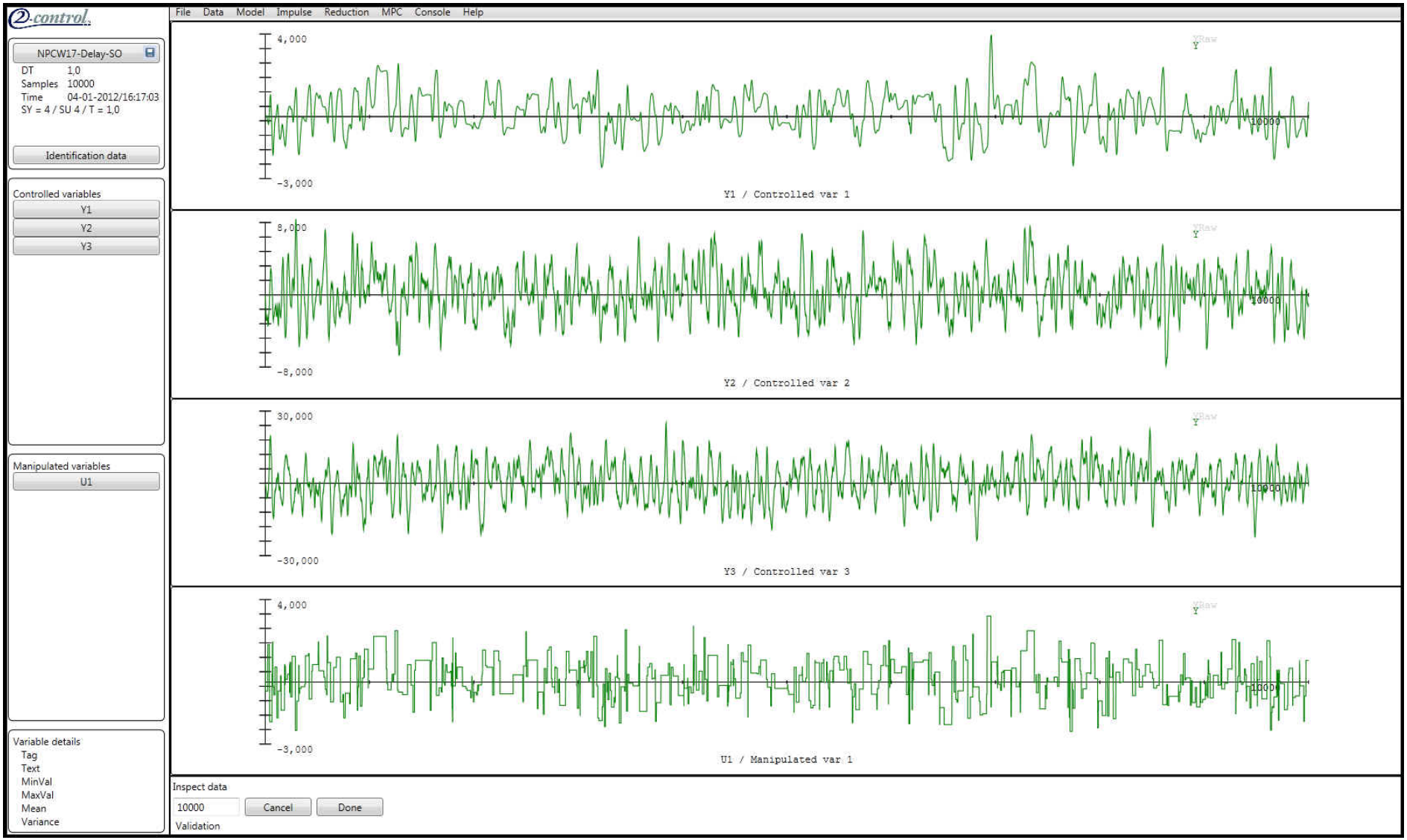


First order ARX processes impulse responses.(SY=1, SU= 6, SD = 1)

Second order ARX, $\sigma^2 = (0.0, 0.01, 0.1)$



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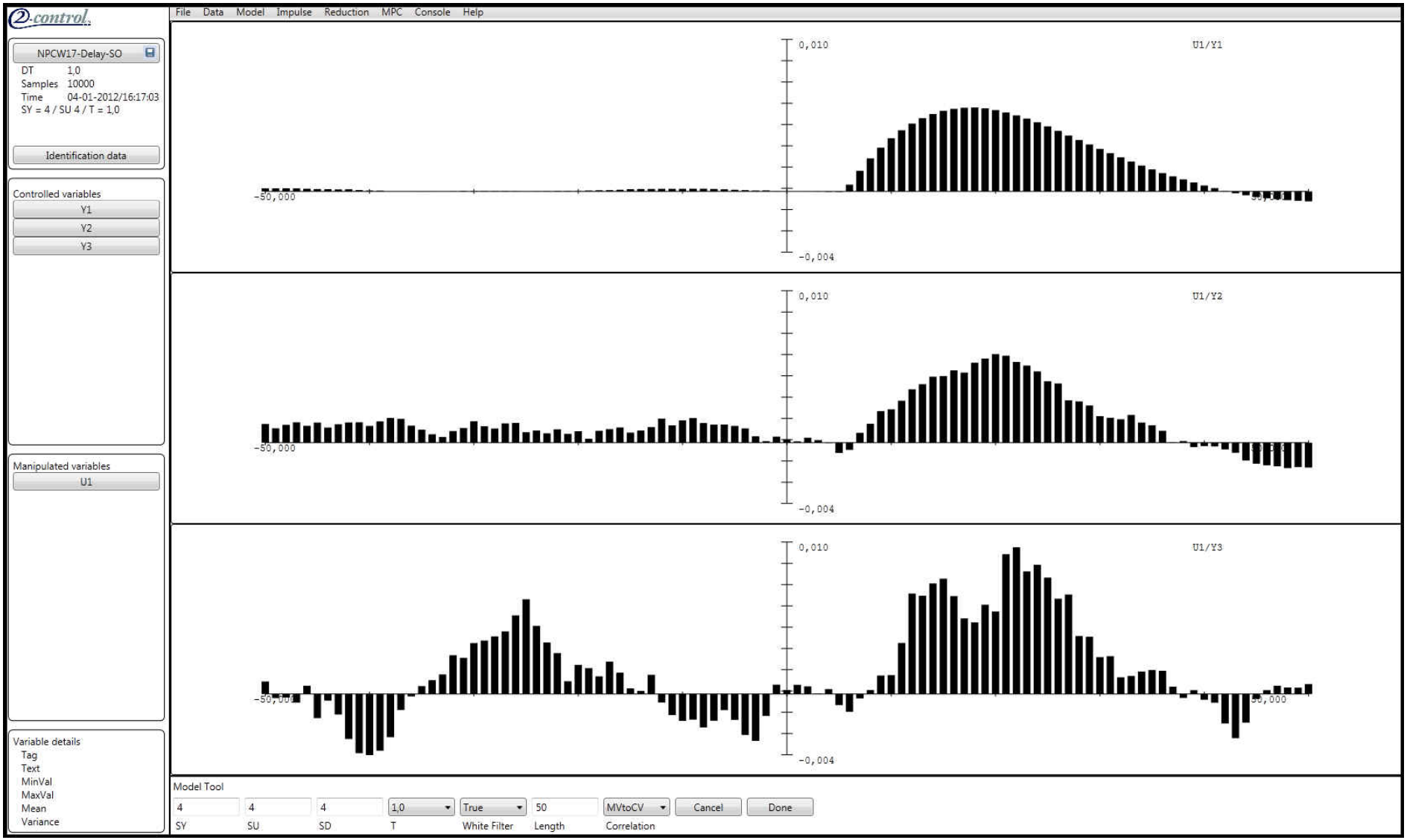

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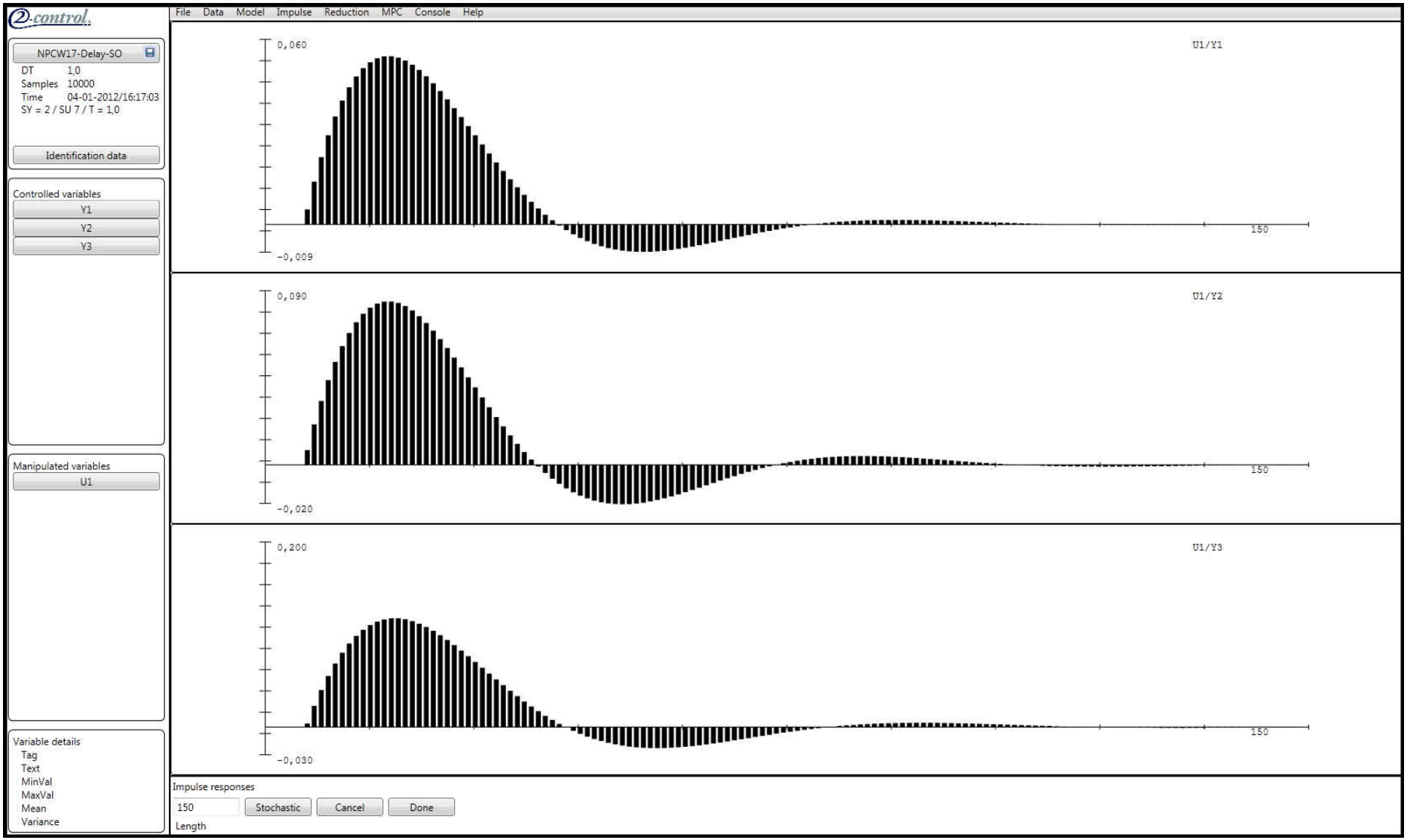

Second order ARX processes impulse responses.(SY=2, SU= 7, SD = 2)

Instrumental Variable Methods

- Regressions using the the $\ell_2, \ell_1, \ell_\infty$ and ℓ_{Huber} norms delivers unbiased estimates if we are dealing with ARX processes.
- If the process cannot be properly described as an ARX process, the estimate will be biased.

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- An example: Second order Output Error process

$$y(t) = \frac{b_1 q^{-1} + b_2 q^{-2}}{1 - a_1 q^{-1} - a_2 q^{-2}} u(t) + \sigma e(t)$$

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- $ModelID$ has implemented the IV4 algorithm, which can be selected during the MISO identifications with the Model tool.

Instrumental Variable Methods. Results

- ℓ_2 norm estimates

σ^2	a_1	a_2	b_1	b_2
0.0	1.7322	-0.7408	0.0045	0,0041
0.01	0.5515	0.3382	0.0028	0,0730
0.1	0.4376	0.4282	0.0262	0,0954

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- IV4 estimates with Filter $= 0.5$

σ^2	a_1	a_2	b_1	b_2
0.0	1.7322	-0.7408	0.0045	0,0041
0.01	1.8953	-0.9048	0.0126	0.0031
0.1	1.9390	-0.9447	0.0126	0,0069

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- $ModelID$ is relatively simple to use for the practical user.
- Future work
  - sub-space methods
  - support for Identification of closed loop data
  - further investigations of Instrumental Variable algorithms

Questions and Comments

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